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MARKET POTENTIALS FOR FATS AND OILS IN SYNTHETIC LUBRICANTS AND LUBRICANT ADDITIVES

Agricultural Marketing Service
UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

This report gives the results of market analyses of farm-produced fats and oils that are chemically convertible to materials usable in industry. Synthetic lubricants for turbine-powered aircraft and lubricant additives for motor oils and greases are covered.

The research on which this report is based was done by Archer-Daniels-Midland Company, and the factual data and analysis were acquired by the U. S. Department of Agriculture through contract.

Methodology and analytical procedures used by the firm in its marketing research were found to be essentially the same as those that the Department would use in such a study.

Supervision of the contract and preparation of the final report were carried out under the general direction of Marshall E. Miller of the Market Development Research Division, Agricultural Marketing Service, U. S. Department of Agriculture.

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DEFINITION OF TERMS

The general chemical structure of diester-based synthetic lubricants can be represented as esters of:

Sebacic acid - $HOOC(CH_2)_8COOH$
Azelaic acid - $HOOC(CH_2)_7COOH$
Adipic acid - $HOOC(CH_2)_4COOH$

with the branched-chained octyl alcohols, such as 2 ethylhexyl alcohol, as the esterification alcohol used. (Esterification is the reaction of an alcohol and an organic acid. Fatty diesters are compounds of a dibasic fatty acid reacted with 2 equivalents of an alcohol.

Octyl alcohol (also octanol or C_8 alcohol) a petroleum derived alcohol containing 8 carbons to each molecule. It is used in various isomeric forms; the most frequent form in diester lubricant manufacture is 2 ethylhexanol.

Mil-L (as a prefix to a specification number) means military lubricant.

Mil-O means military oil.

Mil-C means military corrosion inhibitor fluid.

Mil-G means military grease.

Cn fatty acid - an abbreviated terminology for carbon chain length wherein n is the number of carbon atoms in the compound. Thus, azelaic acid is a dibasic C_9 fatty acid. Carbon chain length of the diester is correlative to lubricant properties and ability of the materials to withstand the conditions under which lubricant must function.

Criticality factors applicable to a synthetic lubricant or lubricant additive are the physical expressions of conditions, such as lubricity, pour point, viscosity-temperature values, oxidation number, and so on, that a material must meet to be usable in the described application. A low criticality use is one in which the conditions of use can be met by a variety of materials. Among synthetic lubricant specifications for aircraft turbine engines, the temperature range over which a lubricant must function without failure is the most critical of the various lubricant specifications.

A lubricant (synthetic or mineral oil) is a fluid which is used primarily to lubricate; a functional fluid serves first to transmit a force and secondarily to lubricate.

The term synthetic lubricant, in this report, means any lubricant other than refinery cuts of mineral oils used for lubricating purposes and natural fats and oils and their metallic soap derivatives. Some oils from petroleum, with special properties, have made up a large part of military purchases of oils for turbine engine lubrication in recent years.

Synthetic oils as used in trade publications includes both synthetic lubricants and synthetic functional fluids. Most of these products are silicate and phosphate esters and polyglycols; they are not fat-derived.

Fat-derived lubricants are principally diesters and are the most important materials in the synthetic-lubricant market.

Centistoke is a unit of measure of viscosity of fluids.

MARKET POTENTIALS FOR FATS AND OILS IN SYNTHETIC LUBRICANTS AND LUBRICANT ADDITIVES

By

Frederick J. Poats[1] and Royce G. Freese

SUMMARY

Synthetic lubricants currently used in turbine engines in aircraft are principally derived from castor oil and to a lesser extent from tallow. Supplies of castor oil come from both imported and domestic sources. Tallow is a cheaper and more plentiful domestic raw material. Also, tallow is a major item in our domestic fats and oils over-supply problem. The amount of castor oil and tallow used for making these lubricants, in comparison with their total supply, is small. Less than 0.2 percent of the tallow supply is used in aircraft lubricants. Also, the maximum market potential for tallow as an aircraft engine lubricant is not large. However, tallow derivatives already developed for this use could provide a market for 10 percent or more of the tallow supply if and when turbine engines are used in automobiles and trucks.

The term "synthetic lubricant" as used in this report pertains to a group of compounds that can be used to lubricate at extreme temperatures. The term excludes major types of petroleum oils, functional fluids which serve primarily to transmit a force (such as hydraulic fluids), and also lubricant additives (materials added in small amounts to oils and lubricants to give them special properties).

When a synthetic lubricant is made from castor oil, 1 pound of castor oil yields sufficient ricinoleic acid to make 1 pound of lubricant. A derivative of castor oil (the diester, di-2-ethylhexyl sebacate) has in the past dominated the synthetic-lubricant market.

When the raw material is tallow, 1 pound of azelaic acid diester lubricant requires oleic acid from 2 pounds of tallow. Adipic acid, another dibasic acid with potential use as raw material for a lubricant, is made from coke or petroleum byproducts. Both azelaic and adipic acid diester lubricants are dibasic acid esters of the same alcohol material that is used in making the lubricant from castor oil.

Azelaic acid can replace sebacic acid in diester lubricants and meet existing needs for lubricants for aircraft turbine engines. Additives with the azelate-base fluid can give the necessary viscosity, load-carrying ability, and oxidation stability to make azelaic acid a lower priced contender for this sebacic acid market. Adipic acid diesters also have been considered, but physical properties limit their use as base fluids of turbine engine lubricants. Costs estimates of raw material, on a 100-percent yield basis, for lubricant type diesters made with dibasic acids and octyl alcohol are: (1) dioctyl sebacate, 47 cents a pound, (2) dioctyl azelate, 33 cents a pound, and (3) dioctyl adipate, 29 cents a pound. Selling prices quoted in 1958 were 60 cents, 45 cents, and 40 cents a pound, respectively.

It is expected that domestic requirements for synthetic lubricants derived from fat materials will increase from the 10 million pounds used in 1957 to a peak of about 26 million pounds in 1961. New turbine engines with higher operating temperatures developed for future military use have lubricant specifications unattainable with fat-derived diester materials. Therefore, a decline in military usage of fatty diester materials is

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expected. Compensating this, increased use of diester-based synthetic lubricants in turbine-powered commercial aircraft is forecast.

At present, the major outlet for azelaic acid from tallow is for plasticizers for use with vinyl resins. About 12 million pounds of azelaic esters are, according to the industry, consumed in this way. Also, the industry expects this market to grow as much as 1.5 million pounds each year until 1965. This use for azelaic acid exceeds its potential use in synthetic lubricants for aircraft. In addition, major new uses for azelaic acid and its esters, such as in the production of films and fibers, may develop in the future.

Pelargonic acid is produced as a joint product when oleic acid (chiefly from domestic tallow and grease) is used to make azelaic acid. Firms with large-scale market opportunities for azelaic acid are concerned that uses for pelargonic will not balance with supplies when companion-produced azelaic acid volume is increased. Finding large volume new uses for pelargnoic acid is a major concern of these firms. As late as 1958, pelargonic acid was in oversupply. Currently, a tight supply situation, on account of newly developed uses, has reversed the market position of pelargonic acid. Profitable azelaic acid manufacture depends upon demand for both azelaic and pelargonic acids.

There are fewer opportunities for developing profitable new uses for fat and oil derivatives in lubricant additives than in synthetic lubricants. The market for lubricant additives is a "mature" one. An innovation acceptable to customers of additives must offer either better performance or lower price than presently used materials. Selling prices of most additives are less than the prices of the fatty acids that would be the starting point for new additives.

Only two additive categories, viscosity improvers and "ashless" detergents, have sufficient price incentive to attract research in materials from fats. "Ashless" detergents are the more attractive of the two, since they are reported to have better sludge-dispersing ability than presently used alkali-containing detergents. In addition, the "ashless" detergents have value as pour point depressants (permitting free flow at lower temperature) and as viscosity improvers. They can replace two or more single-function oil additives.

PART I - SYNTHETIC LUBRICANTS

THE DIESTER LUBRICANTS

While much of research in the United States on synthetic lubricants dates back to World War II, diester-based products have been used in volume only for the last few years. Major growth in use for the diester type of lubricant is expected to develop during 1960-70. The sebacic-acid diester, di-2-ethylhexyl sebacate, has been the dominant base fluid of synthetic lubricants.

Azelates, and possibly adipates of similar diester formulation, can meet many of the requirements for synthetic lubricants, and have a favored competitive position over the sebacates from the standpoint of lower prices and plentiful supplies of domestic raw materials.

Castor oil is the present raw material source for sebacic acid. Azelaic acid is derived from oleic acid, a major fatty-acid constitutent of tallow and grease. Adipic acid is derived from cyclohexane or benzene and is classed as a petrochemical product.

Each of these dibasic acids considered in the synthetic-lubricant market is a versatile chemical-intermediate material, and as such, has a number of competing outlets and uses in chemical markets. Plasticizers for plastics, synthetic fibers (Nylon 6-6 with adipic; Nylon 6-10 with sebacic; and potentially, Nylon 6-9 with azelaic), and

polyester plastics are outlets in which these materials compete. Prices for them in these outlets will largely govern prices for synthetic lubricants.

The market for diester-based synthetic lubricants is fast growing and rapidly changing. Its growth has been dependent upon military jet aircraft development and use in the past several years. Civilian airliners with turbine engines are creating a new market. For the future, increasing use in aircraft, and perhaps in automobiles and trucks, primarily with turbine engines, is viewed with optimism.

In this report each of these markets is considered in detail. The two most significant factors in market considerations are: (1) The prices of synthetic fatty diester-based lubricants in comparison with mineral oils, for large volume, low criticality uses, such as in automobiles; and (2) the technological development of new turbine engines for aircraft that will operate at higher temperatures, and exotic propertied lubricants that will eventually displace diester-based materials when extremely high temperatures are involved.

MILITARY USE OF SYNTHETIC LUBRICANTS

Aircraft Gas Turbine Lubricants

Use of synthetic lubricants for military aircraft will continue as long as jet aircraft are a military "hardware" item. Table 1 gives statistics on military purchases of synthetic lubricants from July 1, 1956 to March 1, 1959. During this period, purchases amounted to about 29.5 million pounds. The impact of the missile program is not yet evident and is indicated only in the "flattening-out" of estimates of purchase volume for the period between 1961 and 1965.

Petroleum-based turbine-engine lubricants (see purchases under specification Mil-O-6081A, table 1) amounted to approximately 25.6 million pounds during the same period. Their use is expected to disappear when the older jet-engined aircraft using them are retired. Accordingly, estimates for 1961 and 1965 exclude materials of this type. A similar decline in military use is predicted for lubricants from fatty diesters covered in the Mil-L-7808 specification. This decline will occur when lubricants under the newer Mil-L-9236 specification become available for use in engines requiring them.

In turbines, fuel efficiency is correlated with operating temperature. More energy is obtained from fuel in a turbine in which high operating temperature is possible. This is a greater factor in turbine-engine operation that cost of lubricants used at the higher temperatures. Neither cooling of the oil, nor using large quantities of oil, are feasible alternatives to seeking lubricants capable of withstanding higher operating temperatures. Cooling the oil would work against fuel efficiency and use of large volumes would work against sustained flight. Mid-air refueling does not and probably never will permit addition of oil at the same time.

Diester-based synthetic oils now in use are not sufficiently serviceable for new engines now being tested which are designed for speed ranges of Mach 2 or above. For these engines, the current specification for oil is Mil-L-9236. In them, bulk-oil temperatures of 400° F. and higher during operation are required. Bulk oil temperatures of diester lubricants in engines now used range from 250° to 300°, close to their maximum heat-stability tolerance level of 300°. For this reason, lubricants for engines that can operate at higher temperatures will require new base fluid materials, and not modifications of present diester fluids that might be achieved by new or different additives to the basic diester-lubricant oil.

A time period extending to 1965 has been estimated in this report as the "market life" of diester-based lubricants for military airplanes. This time could be foreshortened by either (1) rapid development and changeover of aircraft engines to use the higher-bulk-oil-temperature engine; or (2) development of an oil fitting Mil-L-9236 requirements

TABLE 1.--Military purchases of specialty lubricants and greases, July 1, 1956 to February 28, 1959, and estimates of future purchases

Specification		Unit (thousands)	1956-1957[1]	1957-1958[1]	July 1, 1958 to Feb. 28, 1959	Estimated	
Mil. No.	Use					1960-1961	1964-1965
L-7808	Engine oil, gas turbine	Gals.	1,043.50	495.31	1,244.11	2,000	500
L-6085	Instrument oil, low volatility	Gals.	10.60	10.59	0.96	15	15
C-8188	Corrosion preventive oil, gas turbine engine	Gals.	134.80	17.50	89.78	75	75
G-3278	Low and high temp. grease airframe and instrument	Lbs.	453.80	212.60	6.90	250	250
G-7118	Gear grease - extreme pressure, for aircraft	Lbs.	28.60	31.60	32.00	50	75
G-7421	Extreme low temp. grease, aircraft - airframe	Lbs.	15.00	5.00	7.50	10	10
G-15,793	Instrument grease, (Navy) (like Mil-G-3278)	Lbs.	8.60	21.60	0	0	0
G-25,013	Extreme high temp. grease, for aircraft	Lbs.	8.30	0	11.33	20	25
L-10,295	Subzero automotive crankcase oil	Lbs.	0	53.40	0	35	50
	Total diester-based lubricants purchased	Lbs.[2]	10,025.50	4,484.68	10,736.54	17,085	5,130
L-9236	Engine oil, gas turbine	Gals.	0	0	0	1,000	2,500
	Total synthetic oil purchases	Lbs.[2]	10,025.50	4,484.68	10,736.54	25,085	25,130
O-6081A	Aircraft gas turbine oil						
	Petroleum-based grade 1005[3]	Gals.	231.00	255.60	137.85	0	0
	Petroleum-based grade 1010[3]	Gals.	998.40	883.68	688.57	0	0
	Total	Lbs.[2]	9,835.20	9,114.24	6,611.37	0	0
	Grand total	Lbs.	19,860.70	13,598.92	[4] 26,021.87	25,085	25,130

[1] Summary of Procurement Statistics, Military Petroleum Supply Agency, Budget and Statistics Branch, Department of Defense, Washington, D. C. [2] Conversion of gallons to pounds using 8 lbs. to the gallon. [3] Used in post-World War II jet aircraft engines (such as the engine in F-80 type aircraft, obsolete by 1960, even for trainer types).
[4] Estimated annual total 1958-59 based on purchase data for 8 months.

that was the same or lower in price than present Mil-L-7808 (diester-based) oils. This oil would then be expected to fill Mil-L-7808 as well as Mil-L-9236 bid purchases, since it could be eligible under both specifications.

Military purchases of diester lubricants are made according to specifications of the various services (Army, Navy, and Air Force) for specialty lubricants, oils, and greases. A diester-type base material fits the specifications for 15 lubricants. Purchases were made under 9 of the 15 specifications during the period from July 1956 to March 1959; volume statistics are shown in table 1. The services specify what characteristics are wanted in lubricants. The difference between all but two of the nine lubricants that were purchased is in the additive combined with the base fluid. The exceptions are Mil-L-10,295 which is a mineral-oil blended with a synthetic (diester) oil for Army Ordinance use in automotive crankcases for piston engines in sub-zero conditions, and Mil-G-4271, which is a grease classed as a lithium-soap-diester-fluid blend.

In addition to the specialty lubricating materials currently on the purchase list, one other is of special interest to diester producers. This is Mil-L-25,336, lube oil, turbo-prop, for use in aircraft. Turbo-prop equipped military transport aircraft numbers and the volume of future synthetic lubricant purchases arising from their use are too difficult to estimate. Use of synthetic-oil in turbo-props and the market volume potential they represent is limited to civilian airline markets.

The difference between a turbo-jet oil, such as Mil-L-7808, and a turbo-prop oil, such as Mil-L-25,336, is in load-carrying ability. Turbo-props have a much greater load on the gear tooth faces than turbo-jets. This difference in the two oils is achieved by different additives in the same fluid. Thus turbo-prop or turbo-jet oils represent the same type uses for diesters. When turbo-prop engines that will operate at 400° F. are developed, which may occur before military transport aircraft are converted to turbo-props, diester lubricants will no longer be applicable.

Specialty Oils, Fluids, and Greases

Table 1 shows statistics, and estimates on future purchases, for a number of diester-based specialty greases. Approximately 3/4 million pounds of diesters were required to make the various special greases bought. These materials are compounded from a diester-base fluid, similar to that used in the Mil-L-7808 specification. Consistency according to purpose of each lot of grease is achieved with additives.

Foreign Military Use of Diester-Type Oils

In the foreign military market (NATO countries) consumption is estimated to be approximately 9 million pounds per year. European countries currently supply this area with castor oil for sebacate-based lubricants and would logically continue to do so. Foreign military consumption totals are, therefore, not included in table 1. Neither are statistics for United States military purchases from foreign sources of Mil-L-7808 oils (approximately 5,600 pounds in 1957-58 fiscal year).

Prices of Synthetic Lubricants Purchased for Military Use

All purchases of synthetic lubricants for military use are made by contract. Prices include costs of a container and of delivery.

The average prices paid, by type of container, for material purchased under each specification in the 1957-58 fiscal year according to the Summary of Procurement Statistics, Military Petroleum Supply Agency, Department of Defense, were as follows:

Mil-L-7808:	
55 gallon drum	$4.38 per gal.
1 quart can	1.20
1 gallon can	4.71
Mil-L-6085:	
1 quart can	1.06
1 pint can	.70
4 ounce can	.28
Mil-C-8188:	
5 gallon drum	5.83 per gal.
Mil-G-3278:	
35 pound drum	.61 per lb.
8 ounce tube	.85
1 pound can	.70
Mil-G-7118:	
1 pound can	1.70
Mil-G-7421:	
1 pound can	1.74
Mil-G-15793:	
4 ounce tube	.72
Mil-G-25013:	
4 ounce tube	None in 1957-58
Mil-L-10295:	
5 gallon drum	1.08 per gal.
55 gallon drum (16 gage)	1.18 per gal.

Source: Summary of Procurement Statistics, Military Petroleum Supply Agency, Budget and Statistics Branch, Department of Defense, Washington, D. C.

The small unit sizes of containers indicate another aspect of the market for synthetic lubricants. It is a package deal, even for the large military market. Suppliers of materials can anticipate a similar condition in civilian airline markets, where supplies for servicing of aircraft are on a small unit basis and different from supplier-handler operations with piston-engined-aircraft markets.

NON-MILITARY USES OF DIESTER LUBRICANTS

Civilian Airline Market Growth

Almost every major airline in the world has begun replacing piston-driven passenger aircraft with either turbo-prop or turbo-jet aircraft. Table 2 shows a breakdown of orders of foreign and domestic airlines for aircraft for delivery over 1957-63.

The lubricating requirements for turbo-prop and turbo-jet engines, as viewed by engine manufacturers supplying the civilian airline market, are different enough to be given separate analysis.

Introduction of new engines and synthetic lubricants changes the shape of the airline market. The passenger load-carrying ability of the new aircraft is approximately three times that of the piston-powered aircraft because (1) the average ground speed is about doubled, (2) the number of seats is increased, and (3) it is expected that turn-around time between flights and maintenance time can be reduced.

Unless new demands for air-passenger transportation are forthcoming, it is logical to assume that fewer of the new and faster commercial aircraft will be needed than of

TABLE 2.--Number of new aircraft on order in 1957 by foreign and domestic airlines, 1957-1963

Type of plane engine	Year of delivery						
	1957	1958	1959	1960	1961	1962	1963
Medium range, piston-engine:							
Domestic	24	8	0	0	0	0	0
Foreign	83	22	0	0	0	0	0
Long range, piston-engine:							
Domestic	190	68	0	0	0	0	0
Foreign	73	66	0	0	0	0	0
Medium range, turbo-prop powered:[1]							
Domestic	5	33	17	0	0	0	0
Foreign	86	102	71	0	0	0	0
Long range, turbo-prop powered:							
Domestic	0	11	71	12	0	0	0
Foreign	18	34	42	49	10	0	0
Medium and long range, jet powered:							
Domestic	0	6	76	166	6	0	0
Foreign	0	8	57	97	18	0	59

[1] Approximately 150 additional aircraft of this type already in service and not included in these new order totals.

Source: Esso Air World, Esso Export Corporation, June 18, 1958

the piston-powered aircraft now in use. Market growth between 1961 and 1965 for synthetic lubricants (10 percent per year) is primarily based on continued replacement of piston engined aircraft with jet types.

It is estimated that turbine-powered aircraft can haul present air passengers with as little as one-sixtieth of the amount of lubricant that piston-engined aircraft require. (Turbine engines use one-twentieth as much lubricant as piston-powered engines; only one-third as many engines will be needed to do the same job; therefore, one-sixtieth of the volume of lubricants would be needed.)

Two types of jet engines, turbo-jet and turbo-prop, with differences in lubricants these two engines use, are considered in determining the market for lubricants for commercial aircraft. Turbo-jets have engines that use the direct rearward hot airblast generated in a turbine for propulsion and are sometimes called "pure-jet" airplanes. Turbo-props are turbine-engined aircraft that use about 80 percent of the power created by a turbine to turn a propeller. The exhaust from the turbine is utilized as auxiliary propulsion. Since the load of propulsion power in turbo-props must be transmitted by gears to the propeller, the gear lubricant must have much greater load-carrying ability than the lubricant for turbo-jet engines.

Marketing Aspects for Synthetic Lubricants

Aircraft engine manufacturers are large users of synthetic lubricants. They exercise a strong influence on the commercial airline market for synthetic lubricants by insisting, under the terms of their engine sales contracts and guaranties, that the purchasing airlines use only oils approved by them.

Property Requirements

It is understood that engine manufacturers presently use military synthetic lubricant standards, such as for Mil-L-7808c or Mil-C-8188 oils.

Qualified producers listing. --Engine manufacturers purchase their oil requirements only from companies on a "Qualified Producers List" as opposed to buying from anyone whose product meets the given military specifications. To get on this list, interested suppliers submit samples to the engine manufacturer for evaluation. If, after engine tests, the product proves acceptable, the company submitting the product will be put on the engine manufacturers "Qualified Producers List."

Aircraft engine maintenance records on every plane in the country powered by engines from one such manufacturer are reported to be tabulated regularly. Thus, in this manufacturer's records, there has built up a great deal of information on relative performance of various diester-based lubricant fluids as well as on various petroleum-based oils. In these data, sebacate fluids are said to have had a better performance record than the azelate fluids. Quality improvement of azelate-based fluids, through refinement and additives, has overcome this earlier performance shortcoming, and will enable the azelates to become more effective competition.

Bulk oil temperature and viscosity requirements. --Specifications of commercial airlines for synthetic lubricants for turbo-jet engines require oils which will permit engine start-up and operation at -65° F. Sebacate base materials meet their -65°, 13,000 centistoke, low-temperature viscosity specification. The engine manufacturers and airlines are paying a penalty for using oils with this low temperature capability. Oils which enable engine start-up and operation at -65° are less viscous at the normal 250°-300° operating temperatures. Engines have to have heavy gears to withstand operation at lower temperatures and also the thin oils in the normal operating temperatures. Insistence on the -65° low temperature tolerance at present eliminates synthetic lubricants other than diesters and affords opportunity for substitution of azelates for the higher-price sebacates.

Also, there is sound reasoning for continuation of the -65° F. viscosity specification. The jet-powered commercial airliners will fly at altitudes as high as 40,000 feet, and, at this height, they will certainly be exposed to outside temperatures in the -65° range. If asked to "hold" at such altitudes for a time over a closed airport, they would probably shut down two of the four engines to conserve fuel. The need for -65° start-up capability on the part of the oil and engine would then be specific. Accordingly, as long as commercial turbo-jet airliners will not require higher engine temperatures than approximately 250-300° there will be no change from diester based oils for commercial airline use.

Supply and Distributor Facility Requirements

As to suppliers[2], firms already in the commercial airline fueling and lubrication business are in a strong position to market the diester lubricants.

[2] The actual mechanics of selling a lubricant to airlines are awesome. If a new supplier had a synthetic lubricant which he wanted to sell to a commercial airline for use in its jets, he would be required to:

(a) Approach the engine manufacturer, give a complete history of the product, including raw materials, supply situation, and general structure of the product. He would also have to submit complete laboratory test data on his product, and somehow convince the engine manufacturer that the expensive 150-hour test, estimated to cost $200,000 each, should be run on the product. If the potential lubricant supplier failed to persuade the manufacturer, he would have to pay for the test at an independent laboratory.

(b) If all the above steps were completed to the satisfaction of the engine manufacturer, a Civil Aeronautics Board certificate would be granted to test the lubricant for a prescribed number of hours in commercial airplanes. If this final test is passed, the company would then have actually to go out and sell its product to the airlines and supply the product to each of the many airfields that the airline serves.

There is a possibility that synthetic lubricant marketing and distribution for civilian airline use may develop differently from old established lubricant servicing methods. Synthetic lubricants, even to the large military market, are a package item. Airlines themselves could handle purchasing, enroute servicing, and delivery of an item of such small use. Such a system would enable large volume transactions similar to those of the military. In addition, lubricant suppliers would not have to carry out a distribution and servicing system that would be burdensome and costly in relation to volume and dollar value of the product.

Projected Use of Civilian Turbo-Jet Aircraft

Table 2 shows the number of turbo-jet aircraft on order in 1957 for delivery until 1961. Although it is not known when higher-operating-temperature (400° F.) engines will be adopted for airline use, it is assumed that diester-based fluids will be used until more satisfactory lubricants are developed and proven through military testing and use.

Estimates of daily use of commercial turbo-jet engines range from 7 to 15 hours. Turbo-jets are used on longer average flights than turbo-props; an average of 10 flight hours per day for turbo-jets in commercial airline service is used in estimating long-range requirements for lubricants.

Airlines are, as yet, very new to the use of turbo-jets, so data on hourly rates of oil consumption were obtained from the manufacturers' laboratories and Wright Air Development Command, Dayton, Ohio. Turbo-jet engines require only about one-twentieth as much oil during operation as piston engines. The major part of oil consumption that could occur would be from oil changes, leakage, pilferage, storage loss, and deterioration. When engines are tested, stresses are maximum, and oil consumption rates used here are believed to be greater than they will be in actual operation. Manufacturers of turbo-jet engines predict that these engines in commercial use would operate on one-fourth pound per hour per engine.

At Wright Air Development Command's Propulsion Laboratory, actual oil used per 100 hours of testing is recorded. Jet engines of the type for use in commercial planes consistently used 0.7 to 0.8 pound per hour of Mil-L-7808 oil.

Air Force maintenance requirements are that oil be changed every 50 hours on fighters and every 150 hours on bombers. Oil tanks on bombers average 14 gallons per engine and on fighters 6 gallons per engine. Thus, about another 0.7 pound per hour of operation is discarded at oil changes. Also, all synthetic oils go "sour" in storage eventually (that is, lead corrosion indices go beyond tolerances). Military overhaul operational procedures allow oil consumption to go to 4 pounds per hour before the engine is declared inoperative. Previous experience indicates that airlines will pattern their jet-engine maintenance after the Air Force's lengthy experience.

Estimates for 1961 and 1965 commercial airline synthetic lubricant use in turbo-jet powered aircraft are, therefore, based upon an estimate of 1.2 pounds consumption (0.5 pound consumed; 0.7 pound discarded at oil change) per hour per engine and an average of 10 hours of engine operation per day. With 248 aircraft on order for domestic use before 1961, a calculated 4.35 million pounds will be consumed by turbo-jets in 1961.

Engine manufacturers also use large quantities of oil in "running in" and testing new engines; they probably use 2 million pounds per year for this purpose. When this figure is included in the estimate of the amount of diester fluids to be used in turbo jets in 1961, the total is approximately 6.35 million pounds. Sebacates are expected to be the predominant material used, at least through 1961. It is assumed that by 1965 commercial airlines will substitute cheaper azelates and adipates in base fluids or base fluid mixtures.

Sebacic acid is expected to continue in good supply from Germany, and as such, should continue to supply the European airline market for the foreseeable future. The oil

companies that market airline products in Europe also can be expected to use European source materials, primarily sebacic acid derivatives, for their European sales.

The extent to which foreign airlines operating outside the European area will use U. S. or European source materials is not known. Purchases of turbine-engined aircraft for use in these areas have become a substantial part of the world total. From this standpoint, this "third" market could equal between one-third and one-fourth of total civilian airline consumption of synthetic lubricants. With a package product, and airline servicing, azelates from United States producers would have good potential in this market also.

Domestic Airline Usage of Synthetic Lubricants in Turbo-Props

Market Situation

Domestic airlines need both long-range and short-range operational aircraft. Almost all domestic airline companies are purchasing long- and medium-range turbo-props, and some have orders for both turbo-props and turbo-jet powered aircraft.

Also, it is important to consider the worldwide situation with regard to the airline purchasing plans for turbo-prop powered aircraft. A large share of the turbo-prop engines are made in foreign countries. Engine design determines oil specifications and the turbo-prop manufacturers have favored oils of different properties than the U. S. military jet lubricant oil described as Mil-L-7808 type oil. Heavier load-bearing characteristics and greater oxidative stability for turbo-prop oils are the major differences between Mil-L-7808 specification oil for turbo-jets and the turbo-prop engine oil.

Product Types

In the early 1950's, British engine manufacturers developed a specification (DRD-2487) for their turbo-props, requiring 13,000 centistoke viscosity at -40° F. as compared with the 13,000 centistoke viscosity at -65° required by the Mil-L-7808 U. S. military turbo-jet specification. The DRD-2487 specification oil has 7.5 centistoke viscosity at 210° (the normal bulk oil temperature of turbo-props). Later, American turbo-prop engine research also revealed the need for higher viscosity oils at normal operating temperatures than the -65°, 13,000 centistoke specification oil would permit. Foreign manufacturers of turbo-prop engines are understood to have followed the lead of the British Air Force, and also established purchasing specification for their oils based on the -40°, 13,000 centistoke characteristic product.

Turbo-prop engine designers specifications, which cover purchasing of turbo-prop lubricants, require a viscosity of 7.5 centistoke at 210° F., as compared with the 3.0 centistoke requirement in Mil-L-7808 oils, as well as a substantially higher load-carrying ability.[3] Oxidative stability, corrosion, and other requirements are similar.

The best research approach for prospective producers of turbo-prop oils would seem to be to design a base fluid meeting, in itself, the 7.5 centistoke viscosity requirement at 210° F., and possessing inherently good lubricity. Tri-and-tetra-esters, such as those based on stable neopentyl glycol configuration polyalcohols, esterified with short- and medium-chain-length fatty acids, have properties that make them likely candidates for turbo-prop oil uses. At present, there is only one known supplier of an approved turbo-prop oil to the domestic market. The composition of this oil has not been made public.

[3] The load-carrying specification and requirement from foreign engine manufacturers for a turbo-prop lubricant is 3,000 pounds per square inch on the Ryder gear testing machine at 10,000 revolutions per minute at 165° F.--oil-inlet temperature. This compares with the 1,700 pounds per square inch required under Mil-L-7808 and 2,800 pounds per square inch under Mil-L-25336 (the U. S. military turbo-prop specification oil). Thus, if a diester fluid is used as the turbo-prop oil, it must not only be built for viscosity at low and regular operating temperatures, but also must be heavily loaded with lubricity and extreme pressure agents to meet the requirements of the turbo-prop engines used on domestic airlines. It is axiomatic too, that high viscosity does not necessarily correlate with good lubricity properties in a base fluid. No known additive can remedy serious deficiencies in lubricity.

Turbo-Prop Oil Market Projections

The average daily flying time for turbo-prop aircraft is estimated as 9 hours. Some commercial airlines are reported to be scheduling turbo-prop aircraft for 10 hours a day in the air. Assuming oil consumption per hour of flight per engine at 1 pound per hour, (0.3 pound per hour consumed and 0.7 pound per hour for miscellaneous losses including oil changes), it is estimated that domestic and foreign synthetic oil markets for turbo-props will reach 9.4 million pounds by 1961, and 14 million pounds by 1965 (table 3).

TABLE 3.--Market projections for synthetic lubricants among commercial airlines and engine manufacturers, 1961 and 1965

Type of engine	1961	1965
Domestic:	*1,000 pounds*	*1,000 pounds*
Turbo-prop	2,700	4,000
Turbo-jet	4,350	6,400
Engine manufacturers	2,000	3,000
Total	9,050	13,400
Foreign:		
Turbo-prop	6,700	10,000
Turbo-jet	4,000	6,500
Total	10,700	16,500
World total	19,750	29,900

Specialty Oils and Greases

Aircraft equipment and air frame manufacturers as well as the airlines require specialty oils for wheels, instruments, and air frame uses. Consumption is in proportion to engine lubricant use. For this type of use it is assumed that 500,000 pounds per year of diesters for making these oils and greases would be used domestically and a like amount in foreign markets.

Automotive Uses

Use in automobiles is the third major potential market use for synthetic, diester-based lubricants. It is also the most difficult to assess in terms of timing and volume. The possible uses for diester fluids in the automotive field are (1) as functional fluids, (hydraulic fluids) (2) in transmission fluids, (3) in piston engine crankcases when operated in sub-zero weather conditions, and (4) as the gear lubricant in the gas turbine engine that is expected to be used in the auto of the future.

As Functional Fluids

To date, fatty-acid diesters have achieved no major use as functional fluids. Other nonfat-based synthetic materials, such as silicate esters, phosphate esters, and polyglycol mixtures are being used as brake fluids, and so forth, at a rate of approximately 45 to 50 million pounds per year. This is principally non-military business. Key selling points for such synthetic fluids have been low flammability, low compressibility, durability in service and better performance at somewhat higher temperatures. Because of

small replacement fluid sales and higher prices, it is anticipated that synthetic oils of the fatty diester types can obtain no more than 10 to 15 percent of this functional fluid market.

As Transmission Fluids

The conventional "Type A" transmission fluids for present day piston engine automobiles are having heat stability problems. As silhouettes of new cars are lowered, a change to smaller size gears and greater offsets is made to keep the floorboard hump as low as possible. Also, reduced space for transmission gears and for circulation of air around the gear housing lessens air-cooling. Addition of power accessories has caused a weight gain for automobiles, despite use of lighter weight metals. These developments have increased gear loads and raised oil temperatures.

One automobile manufacturer indicated during the survey that his 1959 model car transmissions frequently reach operating temperatures as high as 325° F. Even at 275°, the "Type A" fluids (mineral oils with additives such as lubricity agents, anti-oxidants, corrosion inhibitors, and extreme pressure agents) give trouble from varnish deposits on gear and bearing surfaces.

Despite this, the viewpoint of the automobile manufacturers interviewed was that sufficiently improved fluids and lubricants for gears can be obtained by changes in additives. Substitution of a more stable, high temperature base fluid than presently used mineral oil was not required. The best mineral oil fluids can be obtained for 50 cents per gallon. With tallow at 7 or 8 cents per pound, enough of this raw material for a gallon of synthetic oil, would cost about 60 cents. Without exception, major United States automobile manufacturers indicated that diester fluids and other synthetic oils are too costly to be used as base fluids for gear lubricants and functional fluids for present piston-engined cars. The same reasoning was applied to automotive brake fluids from diesters.

In Crankcase Oils

Again, because they are expensive, diesters have not been strongly considered as substitutes for mineral oil formulations for use in crankcase oils. There has, however, been a surge of interest in so-called "ashless detergents" as lubricant additives. The future of these detergents, while promising, is not yet proven. (See Part II of this report.)

Technical Advantages of Use of Diester Fluids in Automobiles

Even though automobile manufacturers interviewed were pessimistic toward use of diester-type fluids in piston engines, information from other sources indicates that possibility of such use should not be dismissed without further evaluation.[4]

Diester-type lubricants function over a much wider temperature range than commonly used mineral oils. Because of this, uses in arctic temperatures for land vehicles and marine engines, where start-up in extreme cold is followed by normal temperature operation, merit consideration.

Diester lubricants are self-deterging oils and do not "wear out" as rapidly as regular crankcase and transmission oils. Cleaner running, lowered friction and, therefore, longer life to wearing parts, are positive advantages for diester oils. Such advantages are perhaps sufficient to overcome higher initial cost of diester materials.

[4] Reports of military testing and experience during 1948 through 1952 with various types of crankcase transmission and gear lubricants under arctic weather conditions show characteristic performance of synthetic and mineral oils. In 1957-58 fiscal year, 53 thousand pounds of a sub-zero-use oil were bought for automotive and ordinance use by the military forces. These experiences indicate a greater tolerance to operating conditions and better service of diesters than from mineral oils, even with additives and diluents. Further research is needed to evaluate the diester oils for possible wintertime use in automobiles and other vehicles where temperature for start-up is below 0° F.

In a 50-50 blend with mineral oils, diester fluids function much as when used alone. Blending would lower the cost per unit, and yet contribute many of the desirable qualities of a 100-percent diester-based oil.

Further research is needed before an answer can be given to these questions of use for diester lubricants. The possibility that surplus tallow could be used in making such lubricants is attractive.

Almost all of the automobile manufacturers questioned had a different answer regarding the future use of turbine engines in automobiles. Also, none would guess at what type of lubricant such engines will require. The one point on which they were in general agreement was that consumption of oils as lubricants, whether mineral oil-based or synthetic, would be sharply reduced. In tests with turbines suited for automotive use, oil consumption was so negligible that it was not even measured. Thus, turbine engines will consume much less oil than the present piston engines. Also, oil is not used in the combustion chamber, nor is it exposed to hot combustion gases; therefore it remains clean for a long time. With low oil consumption, the oil reservoirs would be smaller. Any condensation of moisture in the oil reservoir will be eliminated the first few seconds the turbine runs because of the high operating temperatures. With diester-type oils, the bulk oil temperature could be as high as 300° F. As in aircraft, higher operating temperature to promote fuel efficiency could be expected in automobile turbine engines, too. All of these factors reduce the importance of the unit price of oil and favor the usage of synthetic lubricants.

Since the one outstanding problem creating need for a synthetic lubricant is the high operating temperature of the turbine gears, fatty ester fluids would be favored among the various types of synthetic lubricants that may be considered. For a bearing temperature of 400° F., with a bulk oil temperature of around 300°, conventional diesters could be used with only moderate changes in additive types. For this, petroleum-based oils would require additional cooling of the bulk oil, and, therefore, reduce the turbine's fuel efficiency. Diesters and other synthetic lubricants likely would be favored over petroleum oils because of fuel consumption conditions present in a turbine and the low rate of oil use.

To estimate the possible magnitude of the turbine-powered automobile market for synthetic oils, the following assumptions are made:

(1) Gas turbine engines in cars will have oil capacity of 3 quarts (about 6 pounds).

(2) Oil addition that may be required, as well as perhaps yearly changing, will consume 9 pounds per year per auto.

Any projection is highly speculative at this time, but it is estimated that by 1965 anywhere from 4 million pounds (1/2 million gallons) to 36 million pounds (4.5 million gallons) of oil will be consumed annually in from 264 thousand to 4 million turbine-powered autos.[5] Because blends of synthetic with mineral oils is a possibility, and delay in adoption of diester fluids also needs to be considered, it is estimated that only 4 million pounds of diesters will be used in this market in 1965 (table 3). Price being a major factor in such use, adipic and azelaic acid diesters would be the logical contenders for the market. The estimated amount of azelaic acid use for this market is 1 million pounds in 1965.

ESTIMATES OF CONSUMPTION OF FATS AND OILS IN SYNTHETIC LUBRICANTS

An average annual volume of 9.3 million pounds of synthetic lubricants was purchased for domestic civilian and military aircraft uses in 1957 and 1958. Projections to 1961 are approximately 34 million pounds, and for 1965, 38.5 million pounds (tables 1 and 3).

[5] The estimate of 264 thousand cars is based on assumption that sport cars only will have turbine engines; 4 million is the estimate in case the major part of the 1965 car output has turbine engines.

TABLE 4.--Average annual volume of diesters used in synthetic lubricants in 1957-58, with estimates for 1961 and 1965

Ester	Average 1957-58		1961		1965	
	1,000 pounds	*Percent of market*	*1,000 pounds*	*Percent of market*	*1,000 pounds*	*Percent of market*
Total diester lubricant used.....	9,300		26,140		21,100	
Azelates.....	300	3	6,275	24	7,400	35
(Azelaic acid required).....	120		2,510		2,960	
Sebacates.....	8,800	95	16,730	64	8,400	40
(Sebacic acid required).....	4,400		8,400		4,200	
Adipates.....	200	2	3,135	12	5,300	25
(Adipic acid required).....	75		1,175		2,100	
Total dibasic acid used.....	4,595		12,085		9,260	
Total fat-based acids.....	4,520		10,910		7,160	
Total nonfat acids.....	75		1,175		2,100	

TABLE 5.--Average annual volume of tallow and castor oil in synthetic lubricants in 1957-58, with estimates for 1961 and 1965

Raw materials	1957-58	1961	1965
	1,000 pounds	*1,000 pounds*	*1,000 pounds*
Tallow.....	520	10,900	12,800
Castor oil.....	9,800	18,650	9,300

While current information indicates that the new Mil-L-9236 oils may be fat-based esters, table 4 covers only present and expected future use of fatty diesters. The volume figures in tables 1 and 3, plus the estimate of 4 million pounds of diester-based lubricants to be used in turbine autos in 1965, give the market picture for domestic diester-based lubricants (table 4). Three-fourths of the 2 million pounds of synthetic lubricants used by engine manufacturers in 1965 is estimated to be Mil-L-9236 type oil. The breakdown in the total market between the diesters of sebacic, azelaic, and adipic acids is based on the assumption that price competition between the lower priced materials and their relative properties as synthetic lubricant materials will cause these shifts from a predominantly sebacic acid diester market during 1961-65.

A yield ratio of 45 percent of sebacic acid from castor oil and 23 percent of azelaic acid from tallow is used. Table 5 gives the use of these agricultural raw materials as indicated from the figures in table 4.

The present and estimated 1965 equivalent of tallow when converted to azelates in synthetic lubricants is only a small part of the total United States tallow supply (table 6).

Despite the small percentages shown, markets for synthetic lubricants are of potential importance to tallow producers. Without the current development and proving in aircraft use, the azelaic acid diesters would not be in a position for a possible move into the automotive market. Automotive consumption could reach 500 to 900 million pounds of diesters annually by 1975 if they were chosen for general use in turbine engines. In turn, if we assume approximately 30 percent of this quantity to be azelates, then, from 300 to

TABLE 6.--Domestic tallow supply and present and estimated equivalent azelates consumption in synthetic lubricants, 1961 and 1965

Item	1957	Estimated for	
		1961	1965
Total U. S. tallow supply (billion pounds)	[1] 3	3.5	4
Present and projected lubricant use as azelates related to total tallow supply (percent)	0.17	0.28	0.32

[1] Domestic use, 1.5 billion pounds; 1.5 billion pounds exported.

550 million pounds of tallow would be needed for splitting. The oleic acid derived would be converted to azelaic and pelargonic acids. The splitting of tallow would also yield stearic and palmitic acid fractions, as well as glycerine, and additional market outlets would need to be found for these joint products.

DIBASIC ACIDS FOR SYNTHETIC LUBRICANTS

Because almost universally, 2-ethyl hexyl alcohol (or Oxo iso-octyl alcohol) is used with each of the three dibasic acids to make diester lubricants, analysis of dibasic acid manufacture is the major item of interest.

Azelaic-Pelargonic Acids Manufacture

Azelaic, a 9-carbon atom dibasic acid, is derived from the ozonolysis of oleic acid. The 18-carbon atom oleic acid is cleaved at the double bond by this process, resulting in one molecule of azelaic acid and one molecule of pelargonic acid (a 9-carbon atom monobasic acid). Oleic acid is presently obtained from tallow. By fractional crystallization techniques, tallow fatty acids are separated into oleic acid and a stearic-palmitic acids mixture. Oleic acid could be derived from tall oil acids if special fractional crystallization techniques could be worked out to give an economical process to separate oleic acid from linoleic acid. Until this process for tall-oil is feasible, oleic acid from tallow will continue to be the material of choice in making azelaic acid.

Sebacic Acid Production from Castor Oil

In 1958, there were three domestic producers of sebacic acid from castor oil. The total production capacity of these firms is estimated at between 17 and 22 million pounds of sebacic acid annually. Sebacic acid in 1958 was the preferred dibasic acid constituent in synthetic lubricants.

From our market analysis, we foresee a general trend in the United States, in diester lubricant manufacture of replacing sebacic acid from castor oil with azelaic acid obtained from tallow for economic reasons. Nevertheless, a German firm has recently put up a new sebacic acid and capryl alcohol manufacturing plant, using castor oil as the starting material. A processing innovation in this new plant permits continuous operation at room temperatures.

Adipic Acid as Raw Material for Lubricants

Since adipic acid is produced mainly for the manufacture of Nylon 6-6 fiber, and Nylon resin molding powder, its uses in diester plasticizers and as a synthetic lubricant material have little effects on its prices.

It is expected that adipic acid will continue to move into its existing markets in increasing volume. Sales of adipates in plasticizers, however, have remained fairly stable. At the end of 1957, adipic acid production capacity was 250 million pounds per year and was expected to be expanded to 320 million pounds per year in 1959.

Diester Prices

As indicated earlier, the bulk of presently consumed synthetic lubricants are fatty diesters. The 1958 market prices on dioctyl sebacate were generally about 60 cents per pound as compared with 45 cents per pound for dioctyl azelate. There are a number of different commercial grades of sebacic acid. The highest grade is required for making Nylon 6-10. The next highest is used for synthetic lubricants, and the lowest for plasticizers. There are indications, from prices paid in military purchase contracts, that dioctyl sebacate may be priced lower for synthetic lubricant uses[6] than for plasticizers. Table 7 summarizes the price relationship between the various dibasic acids and their respective esters.

There is a special situation affecting pricing of these diesters. The shorter the carbon chain length of the dibasic acid, the lower is its price and, also, the lower its proportionate weight ratio in the diester.

Using the ratios in table 7 and the 1958 market prices on the dibasic acids and isooctyl alcohol (23.5 cents per pound), there is little difference in margin between the combined raw material costs of diesters and their selling prices (table 8).

TABLE 7.--Price per pound, in bulk lots, of three dibasic fatty acids and their dioctyl alcohol diesters, 1958

Acid	Weight ratio of acid to dioctyl diester	Price of acid	Price of dioctyl diester
	Percent	*Cents*	*Cents*
Sebacic	48	69	60
Azelaic	46	40	45
Adipic	40	32	40

Source: Oil, Paint and Drug Reporter and trade sources.

[6] Mixtures of diesters, such as sebacates with azelates or adipates is an alternative possibility to lower priced sebacates. If such mixtures meet the specifications, they would be offered at lower prices than an all sebacate-base fluid material.

TABLE 8.--Diester selling prices, raw material costs and manufacturing margins
(August 1958 prices)

Diester	Bulk selling price	Raw material cost	Margin	
	Cents per pound	*Cents per pound (100% yield on raw material)*	*Cents per pound*	*Percent*
Dioctyl Sebacate.....	60	47	13	21.7
Dioctyl Azelate.....	45	33	12	26.6
Dioctyl Adipate.....	40	29	11	27.5

Source: Oil, Paint and Drug Reporter and trade sources.

SYNTHETIC LUBRICANTS OF THE FUTURE

Major consideration has been given to azelaic acid's potential for making diester fluids to compete with sebacic acid esters used in present turbine-engine lubrication. Recognition has also been given to the short duration of markets for these materials as lubricants. New engine designs in the future will require a more capable lubricant. The major new characteristic of the lubricant described as Mil-L-9236 synthetic oil, aircraft turbine, is ability to withstand over 400° operating temperature. This target specification for a new lubricant was set up while sebacates were in full use, and is believed unreachable with them or other diester materials, primarily because of the requirement to have an oil to withstand the high temperature.

The transitional nature of requirements and specifications for lubricants for aircraft makes any market analysis of potentials for a specific class of materials applicable only for a short-run period. Materials now being used in certain types of engines are considered only marginal in performance, and newer, more powerful engines operating at higher temperatures await the development of lubricants to service them. When such lubricants are developed, it is to be expected that present lubricant materials and engines will be rapidly replaced.

Another consideration in the future market situation for synthetic lubricant materials is the price and market structure for present diester-based synthetic lubricants in comparison with newer materials that can meet the higher temperature specification of Mil-L-9236 type oil. It is plain, if this, or these newer lubricants are the same or lower in price than diester type oils, and have plentiful raw material sources, they will take not only the Mil-L-9236 type oil market, but the Mil-L-7808 and similar specification oil markets of the diesters as well.

With these considerations in mind, a supplier or potential supplier of lubricants should aim, as research and development goals, for materials suited to the new specifications rather than for new material limited to specifications of types now in use.

Fat-based materials with higher thermal stability than the diesters are of substantial interest as candidates for the new military specification, Mil-L-9236. Compounds in this group are discussed below.

(1) Esters and polyesters containing neo-pentyl glycol configurations. All such materials lack a hydrogen atom on the beta carbon position. Glycols in the group of interest are pentaerythritol, neo-pentyl glycol trimethylolethane, and trimethylolpropane.

Mixtures of straight and branched chain aliphatic acids such as the monobasic fatty acids in the esters of these glycols show best lubricant properties.[7]

(2) A low molecular weight octanol with a 6-carbon saturated cyclic chain having both a methyl and a methanol group on one of the carbons in the chain, if esterified with a dibasic acid, would satisfy the protected carbon condition and could be expected to have interest as a lubricant material. (The octanol described is reported available in test quantities.)

(3) Pinic acid esters are another source material for Mil-L-7808 type oils and possibly Mil-L-9236 specification oils as well. Industrial development of sources of supply of pinic acid, however, have not occurred to the same extent as the fatty acids of animal and vegetable oil origin or the polyol esters, and this has prevented their testing as potential lubricant materials.

(4) Other materials using fatty-type materials of possible interest because of one or more significant properties, including good thermal stability, are:

(a) Longer chain alcohol diesters of sebacic and azelaic acids with suitable oxidative inhibitors

(b) alkyl-diphenyl ethers[8]

(c) polyesters containing dibasic acids

Non-fat lubricant materials being tested for synthetic lubricants also are factors in considerations of future lubricants and competition new fat-based material must face, particularly in terms of thermal stability properties.[9]

The following list of non-fat materials is not complete, but does cover a number of the more frequently-tested items:

(1) The silicones have been kept out of lubricant uses because of their poor lubricity, and gellation from oxygen absorption. Further modification of the molecular structure to reduce these shortcomings would make them potential candidates.

(2) The silicate esters are like the silicones in lubricity and oxidative characteristics. Various fatty acids, are being tried as esterification acids in making silicate esters to modify those characteristics. Results have been similar to results with blending of materials; the product is no better, or not so good as the original ingredients.

Newer silicate esters and polyalkoxysiloxanes are reported to be superior in lubricity, hydrolytic stability, and viscosity than the silicon containing compounds previously mentioned.

(3) Highly purified naphthenic form mineral oils have, at temperatures above 400° F., better oxidative and viscosity index performance than sebacates now in use. Low temperature properties are not known.

(4) Poly-glycol ethers have a loss through volatility problem at higher temperatures.

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[7] A new chemical for synthetic lubricant use in the 400° F.-bulk-oil-temperature range was announced in Chemical Week, January 21, 1959. It is a trimethylolpropane organic acid ester with selected additives and was made and submitted for testing by Celanese Corporation of America. Another compound of similar triester configuration, believed to be based on neo-pentyl glycol, was also successful. It was submitted by Heyden-Newport Chemical Corporation.

[8] This material and others (see item 6 on non-fat-based materials) are discussed later under radiation-resistant high-temperature lubricants.

[9] Dr. M. R. Fenske and others at Pennsylvania State University, have reported on a number of these non-fat lubricant materials in Fluids, Lubricants, Fuel, and Related Materials, M. R. Fenske, et al, Parts I, II, and III WADC Technical Report 55-30, U. S. Air Force, March 1955. The oxidative deterioration values at 400° F. levels were among the critical factors being measured.

(5) Chlorinated bi-phenyls are strong contenders in the 500° F. and upward use range. However, their attack on rubber and other chlorine sensitive materials, and a 20° pour-point are drawbacks.

(6) Newer materials are being developed and tested for radiation resistance as well as for lubrication properties. Among these, one fatty material, alkyl diphenyl ether, with the alkyl's carbon atom number ranging from 14 to 16, has already been listed. On July 28, 1958, the Air Force announced the development and evaluation of a series of poly-phenyl ether compounds for lubricants that have a servicability range of 20° to 500° F. In these materials, radiation resistance was attributed to aromatic structure, and good viscosity, pour-point, and oxidative stability to chain length and oxygen content.

In addition to the specification requirements affecting the structure and applicability of lubricant materials to the aircraft lubricant field, it is necessary to consider other aspects of the material as "in-use" conditions. To be ideal, a lubricant should be stable in air, storable, and easily handled under a wide range of temperature conditions and in a variety of container materials. It should be non-toxic and non-irritating to personnel handling it as a fluid or breathing its combustion products. The ideal fluid, for easy recognition, should also have a characteristic odor and color different from other fluids used in the aircraft.

The fluid must be such that spilling it on parts of the aircraft, such as wiring insulation, flexible couplings, metallic surfaces, and rubber tires will have no deleterious effects.

A disadvantage in any one of these areas can very well eliminate a fluid from use as a lubricant material for both military and civilian aircraft.

PART II - LUBRICANT ADDITIVES

TYPES OF ADDITIVE CONDITIONED LUBRICATING OILS

Because lubricating oils have a wide range of application, it is important to define areas covered by this analysis.

The heart of the additive market is the auto crankcase oils. Substantial quantities of additives are used, however, in industrial lubricants and aviation oils. The following classification of oils spells out the importance of the different uses.[10]

	Percent of total market
Automotive oils (that include auto crankcase oils, heavy duty truck and tractor oils, diesel engine lubricating oils, and gear oils)....	50.7
Aviation oils	1.4
Industrial oils (that include gear oils, turbine oils, marine engine oils, soluble oils, and cutting oils)	35.8
Miscellaneous oils	12.1
Total	100.0

Anti-rust or corrosion inhibitors, and anti-oxidant additives are used in almost all lubricating oils. Anti-foam agents and pour-point depressants (materials that lower the temperature at which materials flow) also are used in many gear lubricants.

[10]The most recent American Petroleum Institute figures on lubricating oil sales were for 1951, published in 1954. In 1951, 44,103,000 barrels were sold.

Table 9 shows the classes of materials used in lubricant additives. Prices of only two of these are attractive to fatty derivative research and development. They are polyester type "ashless" detergents and polymethacrylic esters of fatty alcohols as viscosity index improvers.

Oiliness agents, a fifth category of oil additives, is not shown in table 10. This is the smallest market group, $4 million volume in 1956, and materials used are low priced products of

TABLE 9.--Estimates of price and cost per pound of lubricating additives, by type (100 percent active basis)[1]

Product	Raw material cost	Selling price
	Cents	*Cents*
Detergents		
Mahogany sulfonates	[2] 5-10	10-20
Calcium salts of alkylaryl sulfonates	7-14	14-22
Phenol compounds	[2] 18-24	20-30
P_2S_5 treated butylene polymers	15-20	20-30
Polyester "ashless detergent"	50-55	[2] 70-85
Anti-oxidants		
P_2S_5 treated olefins and terpenes	[2] 5-15	15-30
Metal dialkyl (C_4-C_6) dithiophosphates	15-20	25-35
Viscosity index improvers		
Polymethacrylic ester of fatty alcohols	40-50	70-90
Polymerized butylenes	[2] 18-26	30-40
Pour-point depressants		
Waxyalkylated naphthalene	11-15	15-25
Waxyalkylated phenols	15-25	25-35

[1] Effort was made to exclude all the cost of the base stock oil in determining the 100-percent-active prices shown.
[2] Estimated from either selling prices or raw material costs.

TABLE 10.--Additive use per unit volume of lubricating oils[1]

Oil type	Detergent	Oxidative inhibitors	Oiliness agents	Viscosity index improvers	Pour-point depressants
Passenger car	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Regular	0-0.5	0.4	0.1-1.0	0.0- 0.5	0.1-0.5
Premium	4.0	1.6	.1-1.0	.5- 5.0	.1-1.0
Multigrade	5.0	1.6	.1-1.0	5.0-10.0	.1-1.0
Heavy duty (truck and tractor)	7.8	1.5	.1-1.0	5.0-10.0	.1-1.0
Diesel engine	10-12	0.4-2.0	.1-1.0	([2])	([2])

[1] Use levels are on a 100-percent active basis. Aviation, turbine, and marine-engine oils, as well as all industrial and automotive gear lubricants and functional fluids, are excluded.
[2] No reported use at present.

Source: Estimated from trade sources.

fats and oils. Sulfurized sperm oil, hydrogenated castor oil and simple fatty esters, such as methyl esters of medium and long chain length fatty acids (C-12 to C-18) are used as these oiliness improvers. Tall oil esters, a cheaper material than the animal and other vegetable source fatty acid esters, are taking an increasing portion of this small and relatively stable market.

From 1955 to 1958, multigraded oil sales for passenger cars and light trucks expanded from an estimated 125 million gallons to over 250 million gallons. Total passenger car and light truck type oil sales are estimated to have grown from 545 million to 630 million gallons during this same period. Regular and premium grade oil sales for this use declined about 30 million gallons.

Trade sources indicate a number of factors that cause the lubricant additive market to be termed a "mature market." These factors are:

(1) Use of oil per auto has declined because of fewer oil changes, smaller crankcases, and growth in relative numbers of small cars.

(2) Further growth in use of additive conditioned oils will occur largely through further attrition in sales of regular and premium grade oils. Their replacement with multigrade oils is less than 1-to-1.

(3) Prices of additives, and additive raw materials (table 9) are insufficient to attract potential producers and suppliers of fatty derivatives to undertake the extensive and costly research and development necessary to place a new product in this market.

(4) Possible future developments in the auto industry, primarily in turbine powered cars and trucks, and in oilless bearings, will drastically reduce the lubricant needs per unit and the total market as well. One or both of these changes could occur in the same amount of time required for a supplier to test and develop a new additive.

CONSUMPTION ESTIMATES FOR LUBRICANT ADDITIVES

Individual or blended lubricating oil additives are purchased by the formulator, preferably in the form of mineral oil concentrates. Active additive content in concentrates ranges from 20 to 50 percent.

Lubricating oil production is a continuous-flow operation. Fluctuations in dewaxing or extraction efficiency by the refinery are remedied by adjustments in dosage of viscosity improvers and pour-point depressants. Dosages of other additives are changed only to meet new requirements or specific needs. Not only do concentrates of lubricant additives vary in active ingredient content, but amounts of additive used in a specific lubricating oil will vary. Market analysis of estimated poundage figures was made by taking dollar volume of additives sold and dividing this figure by the mid-points of the selling prices (table 9).

LUBRICANT ADDITIVES AS A MARKET FOR FAT-BASED MATERIALS

The chief interest of fats and oils producers and processors in the lubricant additive market appears to be in the development of "ashless" detergents, and in polymeric viscosity improvers.

"Ashless" detergents could replace metallic salts of alkylaryl sulfonates which have about a 20 million pound annual market. Ashless detergents are reported to be superior to the alkali-sulfonate material in dispersing sludge; therefore they would be used at lower than the 5-percent concentration of detergent now used in multigraded oils. They also possess dual functionality as additives, acting as viscosity improvers as well. Their higher price, 50 cents a pound more than the alkylaryl sulfonates and 40 cents a pound

more than the cheapest viscosity improvers, will be a disadvantage toward widespread acceptance and use. But lower dosage rates and potential replacement of polymethacrylic esters as viscosity improvers are the advantages that can lead to their expanded use.

Standard Oil Company's patent number 2,764,551, issued September 1956, describes an "Ashless Detergent Additive for Lubricating Oils." It is a complex ester formed by the reaction of a dibasic acid with a glycol and an aliphatic alcohol. Dibasic acid from castor oil or tallow derived azelaic acid could be used to make this or a similar type material.

Polymeric materials used as viscosity index improvers are of two main types. Polyisobutylenes (from petrochemical sources) and more recently developed polymethacrylic acid esters of lauryl (coconut oil fatty alcohol) and stearyl (tallow derived stearic acid) alcohols. A third type of material undergoing evaluation for this use is polyvinyl esters of stearic acid.

As with the ashless detergents, the fat derivative materials have a price disadvantage compared with other materials in use. Improved functionality, leading to lower material requirement per unit of oil, and additional functionality (they act as pour-point depressants as well, since they reduce wax crystallization at low temperatures) are in favor of the polymethacrylates and the polyvinyl stearate.

Viscosity improvers are currently estimated to be a 115 million pound market. About half of this market is now made up of polymethacrylates. Further growth depends upon the growth in use of ashless detergents which, by their dual functionality, would logically displace the polymethacrylates in use since they are the highest priced viscosity improvers.

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